# Distributed Reconfigurable Robots

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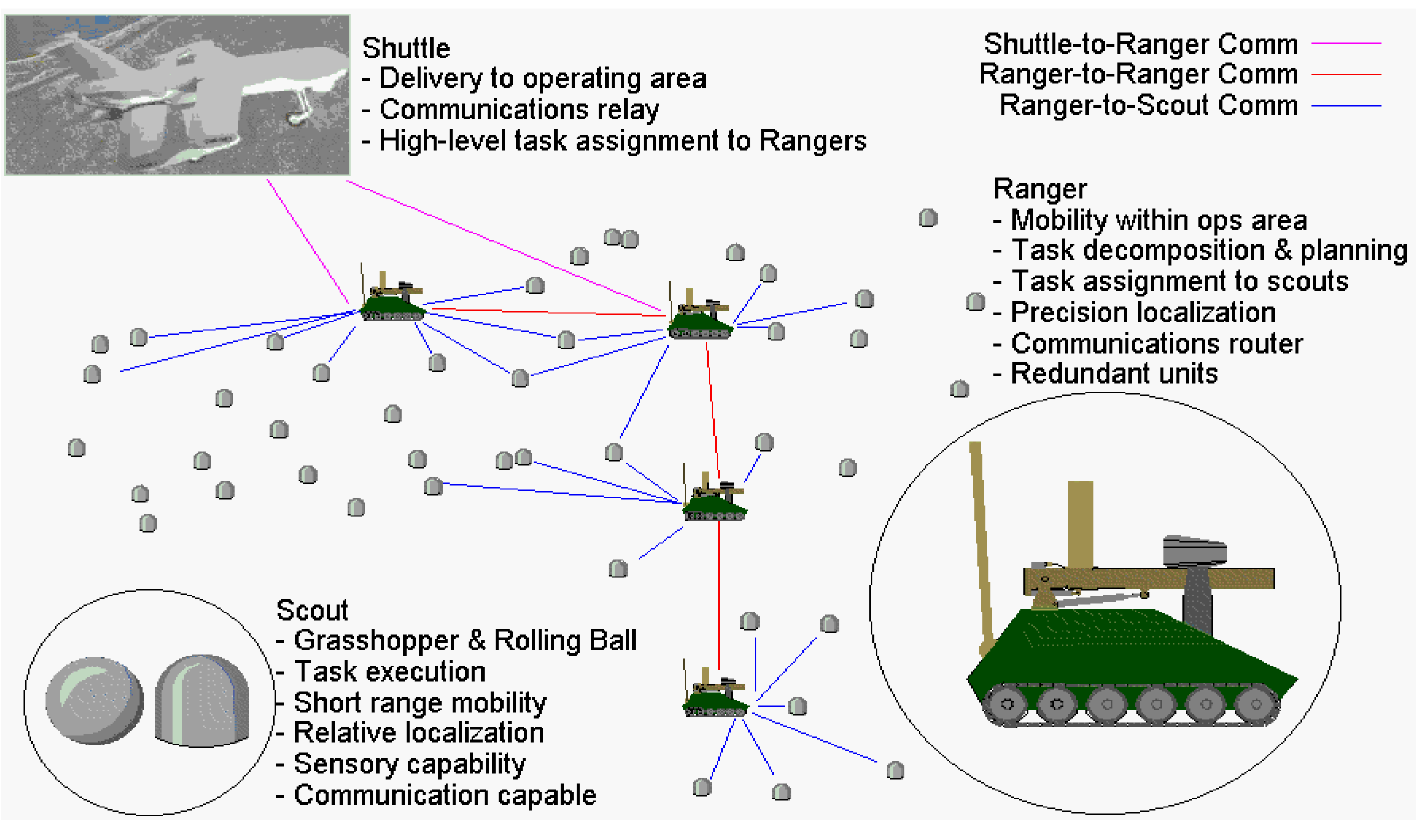
This work involves the design of a novel distributed robotic system which is made up of a large collection of medium size, small, and miniature robots all connected by a wireless communication network and cooperating to accomplish their given mission. The design of the individual robots, in particular the miniature robots, the development of innovative MEMS sensors for the miniature robots, and the development of appropriate control software for the individual robots and the overall distributed system are the major innovative claims of this research. The emphasis of this research effort is the creation of inexpensive reconfigurable robotic systems consisting of physical units that are physically distinct but connected by information. These units have flexible interfaces allowing real or virtual formations of various complexity. They can work independently but can also cooperate for the completion of a common goal. The ultimate hope is that the individual units can accomplish a class of tasks more robustly and cost-effectively than a single robot. The challenge of the project is in rethinking certain classical robotic issues in order to make full use of the capabilities of the individual units.

The system architecture we propose (see figure) consists of four types of robots, a large transport vehicle (the ``shuttle"), a medium transport vehicle (the ``ranger"), and two types of ``scouts" (the ``rolling balls" and the ``grasshoppers"). The maximum dimension of the scouts will be 5 cm.



Managing the deployment of a system of many autonomous robots with varying capabilities and sophistication in a hostile environment requires a sophisticated control architecture. Because of the inherent uncertainty in operating autonomous units in an unknown environment, the control system must be capable of real time decision making and handling of unexpected events. The control functions should be carried out with only limited communication and computation requirements, and the control system should be robust to the failure of individual communication and processing nodes. The control architecture we propose is based on behaviors, and includes the ability, at the higher levels of the control architecture, to negotiate and redistribute tasks as the need arises. All the behaviors provide the capabilities necessary for several diverse applications (exploration, reconnaissance, etc). The proposed control architecture addresses several critical issues, such as task decomposition (automatic versus human-control), use of homogeneous units versus specialized heterogeneous units, and trade-offs among size, power requirements, and specialization.

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# Distributed Robotics Using Reconfigurable Robots

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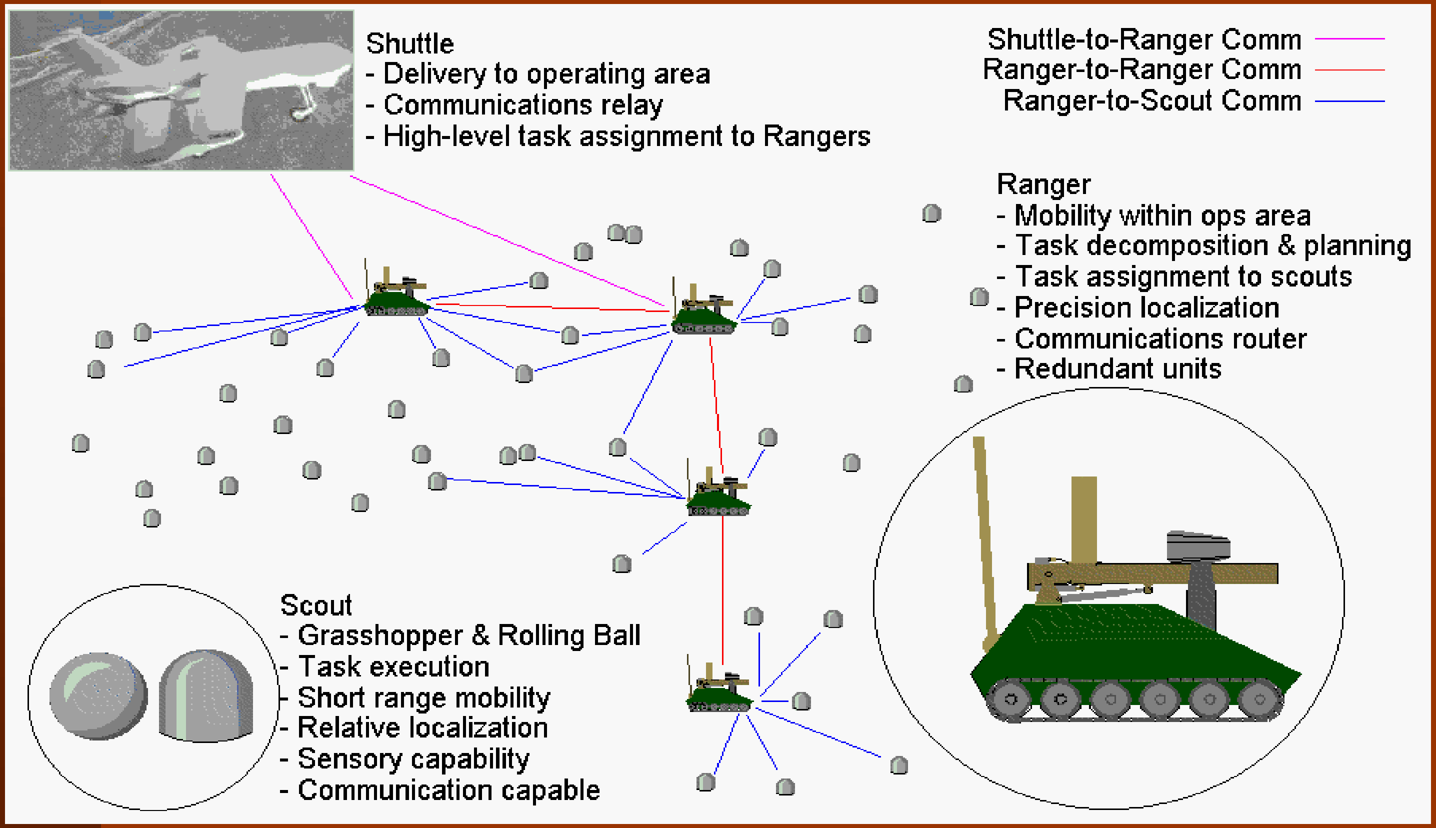
# Target Applications

- **Clandestine reconnaissance and surveillance**
- **Military operations in urban terrain (urban warfare)**
- **Potential for specialized applications such as carrying explosives,  bridge demolition, and destroying barbed wire**

***Exploit the Porosity of Defenses***

# Proposed Architecture



# Three Levels of Hierarchy

- **Scout (~5 cm)**
- **Ranger (~60 cm)**
- **Shuttle (~6 m)**

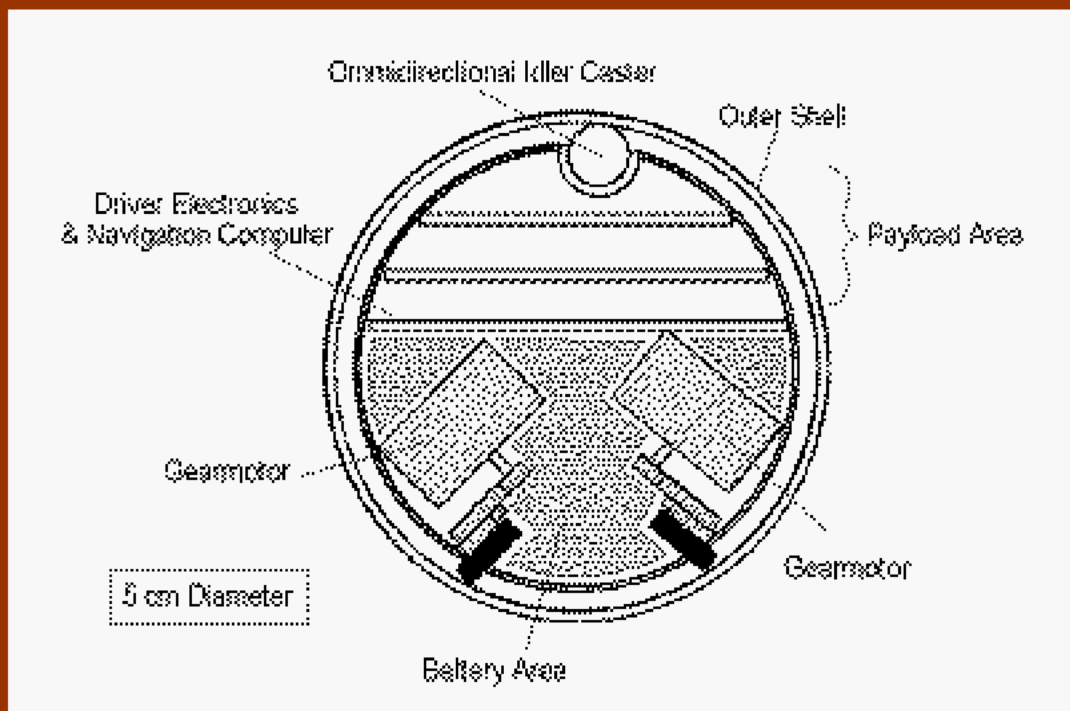
**Emphasis of the Project**

# Shuttle/Ranger/Scout in NASA Terms

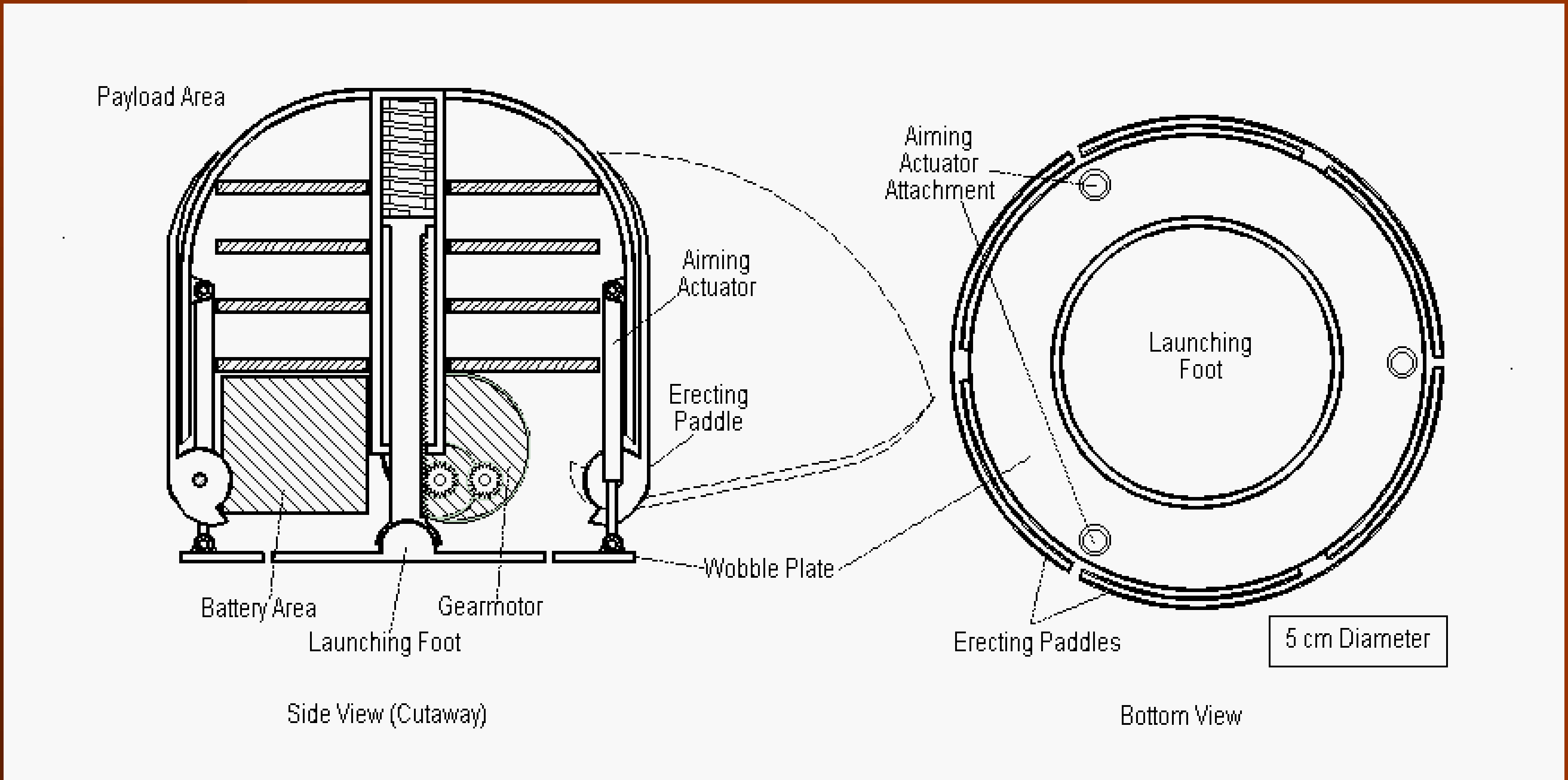

# Scouts

- **Rolling Balls**
- **Grasshoppers**

# Rolling Ball Design



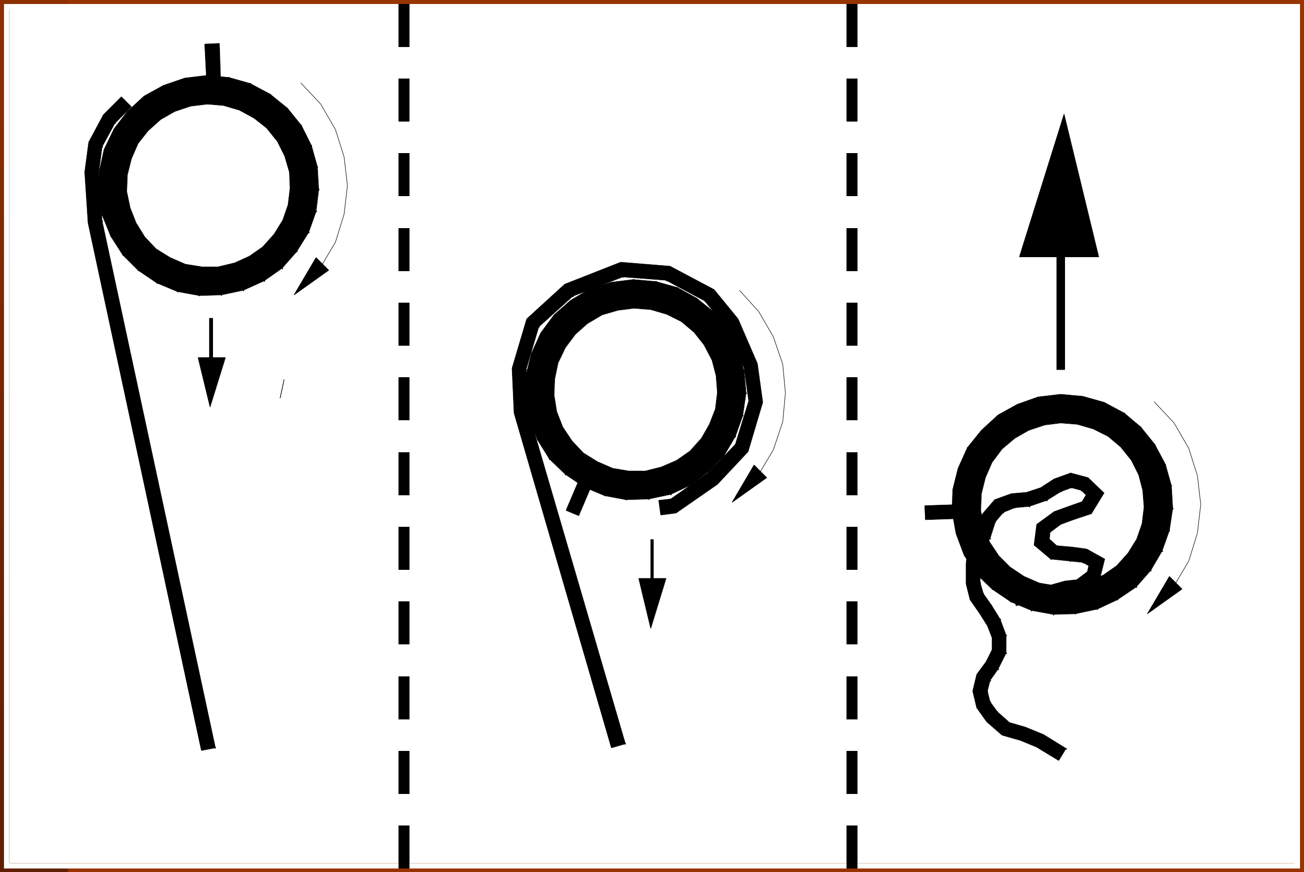
# Grasshopper Design



# Alternative Hopper Demonstrator

MTS is filing a patent application for the concept

# Hopper's Spring Winder



# Initial Hopper Locomotion Power Budget

- **Batteries for 100m traverse consume ~5% of scout (volume and mass)**
  - **Total scout mass: 200 g (5 cm diameter)**
  - **100-hop range (max hop of 1.2m)**
  - **Efficiencies: motor 40%, spring 2 x 80%, foot coupling to ground 70%, flight 80%**
  - **3 paddle actuations (62% of total hop power)**
  - **Lithium batteries (~1000 J/cm$^3$) = ~4cm$^3$, ~8g**
- **Error of 10x yields 50m at 25% of scout**

# Initial Scout C&C Power Budget

- Communication and computation can consume 100mW each, but can be duty-cycled
- 10% of space budget yields 11 total hours of continuous operation
- Solar cells alone can provide up to 3 hours of operation per day (if they survive hopping)

# Current Scout Power Plan

- $Li/MnO_2$ (Lithium Manganese Dioxide) off-the-shelf batteries planned for scout (good power density, good peak current)
- Two DL1/3N cells can power several hundred hops or 16 to 20 hours of standby operation (radio receiver & CPU active)
- Each DL1/3N cell uses 1.13 $cm^3$ volume and each scout can accommodate six to ten cells

# Integrated Hopper/Roller Design

# Innovative Aspects of Scouts

- **Locomotion/mobility techniques**
- **Orientation & localization**
- **Communication**
- **Loosely-coupled collaboration**
- **Precision mechanisms & packaging**

All of these aspects require substantial research and successful innovation during the program!

# Scout Sensors and Communication Components

- **Compass subsystem (magnetometer, tiltmeter)**
- **RadioNavigation/communications technology**
- **Telescopic microcameras**
- **MEMS sensors**

# Compass Subsystem

- **Commercial miniature hybrid magnetometer**
- **Commercial solid state (accelerometer) tilt sensor**
- **Remote compass processing**
  – Shares existing processor, reducing cost, weight, and power consumption on scout.
  – Makes tilt measurement available for scout control system.

# Communications

- Communications network to support RadioNavigation of scouts by incorporating a time of arrival (TOA) measurement capability in rangers.
  - A scout transmits a bit sequence which is received by several rangers. Each ranger determines when this signal was received.
- Based on a star architecture, where scouts communicate with rangers.
  - Optional task to incorporate a mesh architecture, to allow scout to scout communications.

# Communication Innovations

- **Embedded information/error-coding**
  - Reduces transmit power required
  - Extends range of effective communications
- **Custom conformal antenna technology**
  - Physical space constraints
  - RF link requirements
- **Software for navigation and communication control**
  - Operation/control of individual units (scouts, rangers)
  - Coordination with Ranger communications network

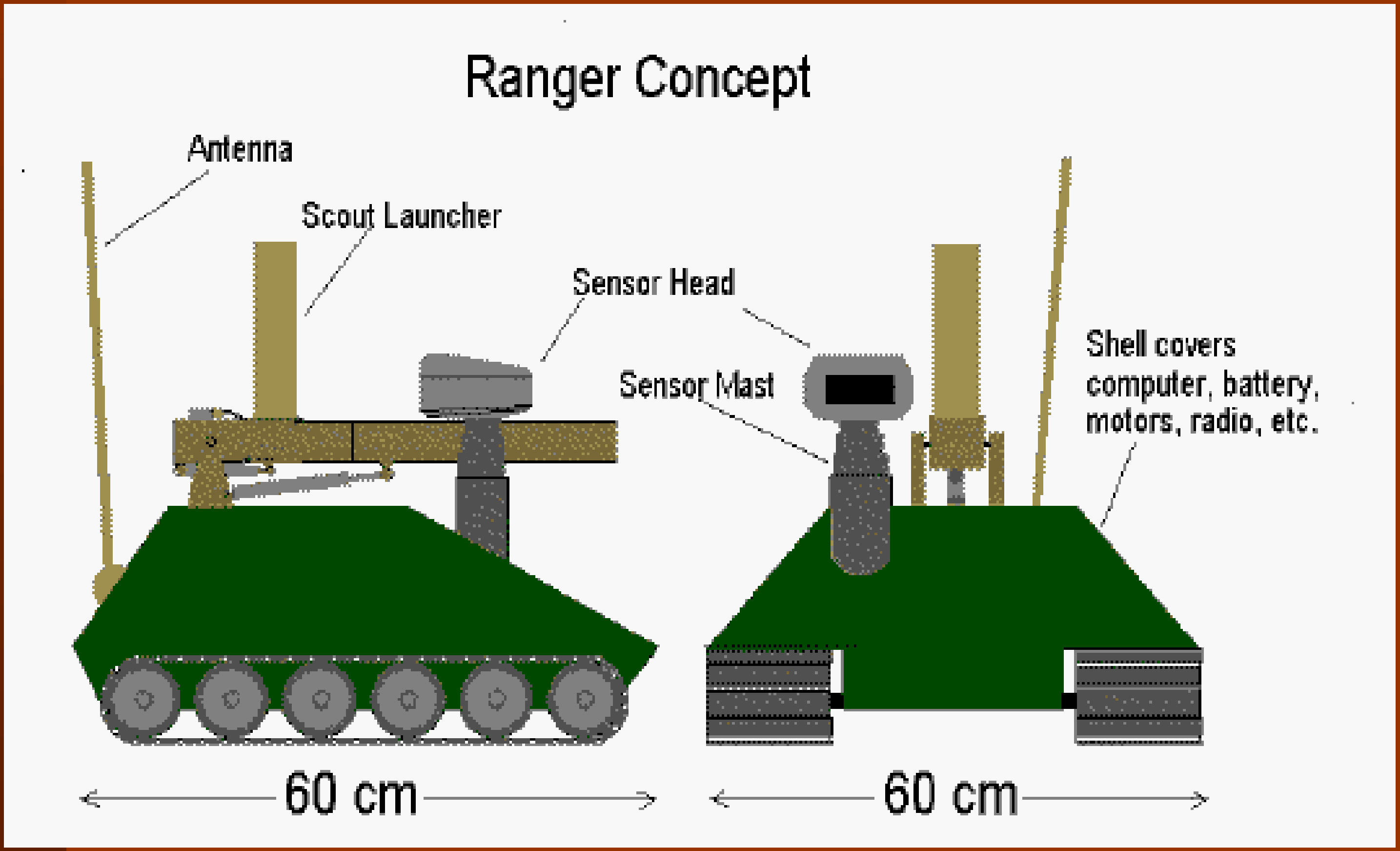
# TDOA for Scout Localization

- Rangers will have GPS capability and have Relative GPS (RGPS) solutions computed for each other, including relative time offsets
- When requested, a scout will transmit a “pulse”
- Each ranger will receive the pulse and determine its time of arrival (TOA)
- Any or all rangers where all TOA data are made available (shared) can then form TDOA measurements
- Since each ranger will use its local GPS receiver for known time information, each TDOA measurement will be corrected for the RGPS-computed time offset between receivers
- RGPS position solutions along with TDOA measurements will be used to compute scout location by using the TDOA algorithm
- This process is repeated for each scout

# Difference From Other Work

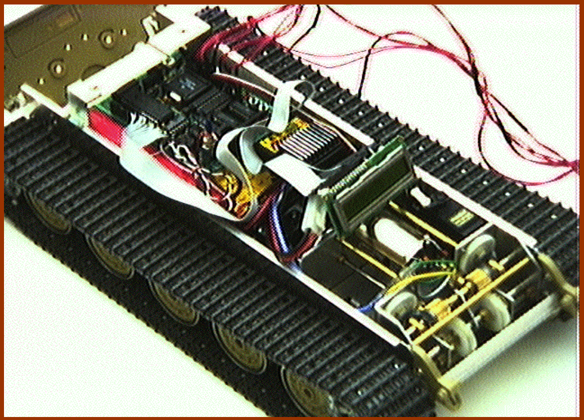
- Previous TDOA systems have been cellular phone based and used fixed cellular phone receiver stations as the TDOA receivers
- This system will allow for mobile TDOA receiver sites (rangers)

# Ranger Concept



# Ranger Platform

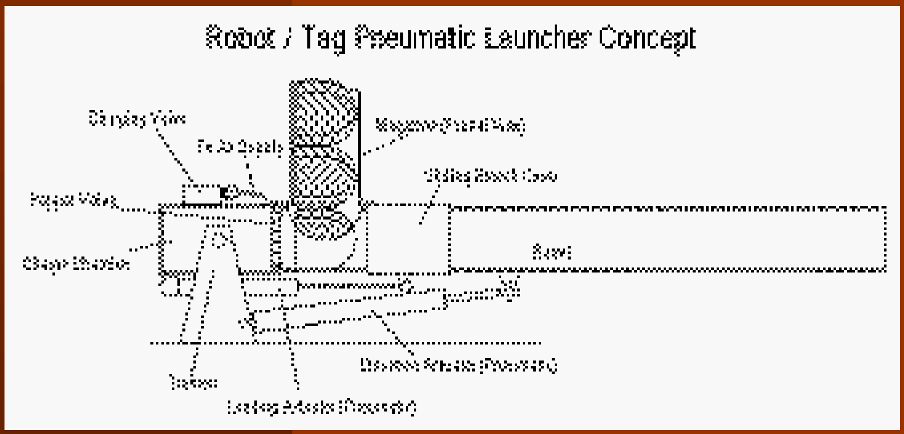
ATRV-2 from RWII

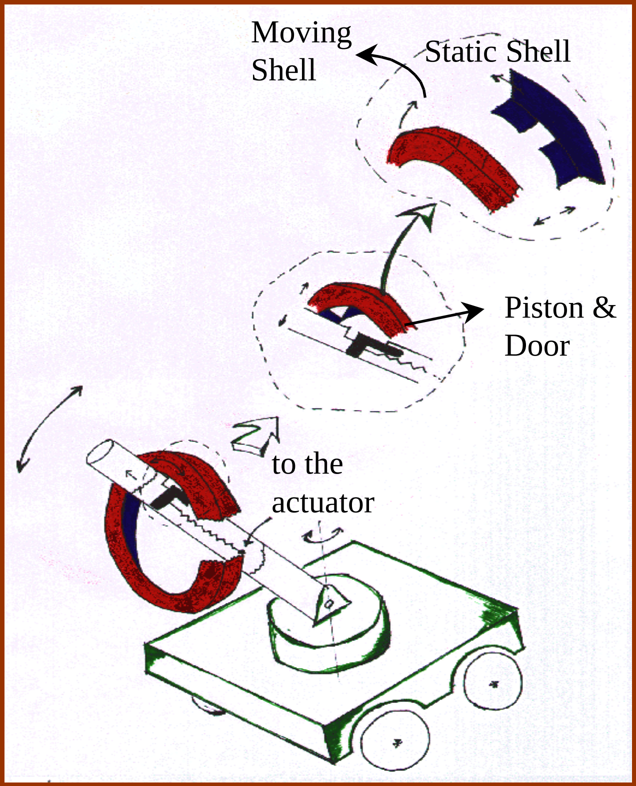


R/C Tank from Tamiya

RWII has designed with us the ATRV-Jr. An order for four units has been placed.

# Launcher Designs



# Nomadic Routing

**Task: Develop a Nomadic Network Router approach for a distributed collection of heterogeneous mobile robots (ranger, scout)**

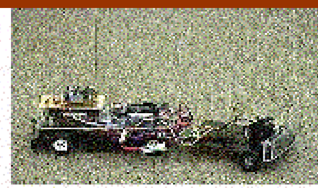
- Each robot (with communication module) is a potential router node;
- Objective: quickly adapt the network routing as robots maneuver through a mission operations area;
- Tolerant of both communications or robot failure;
- Maintain end-to-end connectivity across the nomadic robotic network
- Adapted to reconfigurable robot communication hardware and protocols

# General Innovation Items

- Design and functionality of the scouts
- Design of the ranger-scout system (launching, communication, navigation)
- Simple control and communication primitives that can be reconfigured for a variety of robot behaviors
- Development of a large (44 agents) heterogeneous distributed robotic system based on these scalable, reconfigurable behaviors and physical components
- Miniaturization of the scout hardware peripherals (e.g. sensing, communication, etc.) will require innovation
- Development of innovative MEMS sensors for a specific target application (e.g. molecular recognition, micro-vibration, etc.)

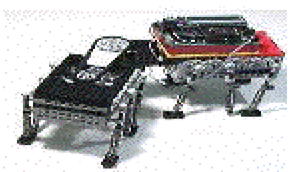
# Robot Examples from the University of Minnesota

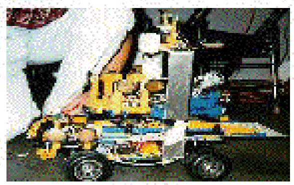

Pole Balancer
6 / 94
Reinforcement learning for control, app 1.


Original Trailer-Backer
8 / 94
Reinforcement learning for control, app 2.


Walleye
8 / 95
Vision-based object retrieval.

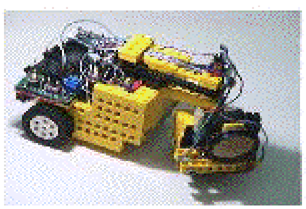

6-Leg Walker
3 / 96
Simple mechanism for legged mobility.


12-Leg Walker
4 / 96
Controlled legged navigation.

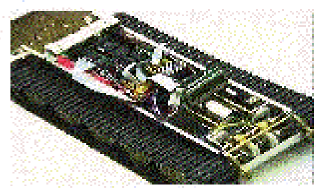

Loon
8 / 96
Distributed navigation and mapping.

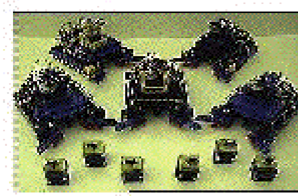

Baby Loon
8 / 96
Navigation and mapping.


Photovore
11 / 96
Reactive behavior control.


Surfbot
3 / 97
Potential field navigation.


Trailer-Backer II
8 / 97
Reinforcement learning for advanced control.


Prototype Ranger
3 / 98
Command agent for distributed robotics system.

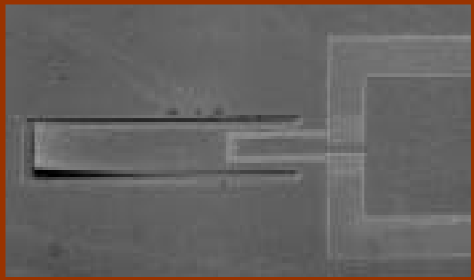

MinDART
6 / 98
Multi-agent mapping, search and retrieval.

# Control and Simulation

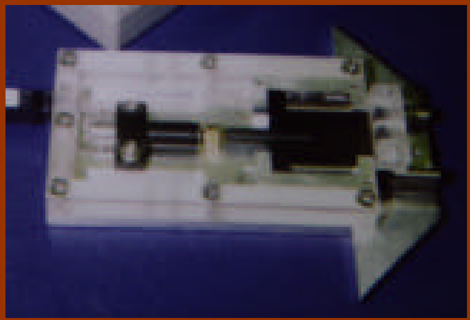
- Control architecture is layered and based on behaviors
- Rangers are the control and communication central units (utility units)
- Simulation environment for initial rapid testing
- Lego-based platforms are used for rapid prototyping and experimentation

# MEMS Projects: Biosensors, Micromotors, Vibration Monitors

- **Molecular Recognition Biosensors**
  - MEMS-Based Microcantilever Beams



- **Precision Micromotors**
  - Piezoelectric Micromotors
  - Electromagnetic Micromotors



- **Vibration Monitoring Devices**
  - Microcantilever Beams, Interface Electronics,
  - and Telemetry